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PRESERVATION OF MEAT AND DAIRY PRODUCTS BY HIGH ENERGY RADIATION

Eastern Utilization Research Branch
Agricultural Research Service
United States Department of Agriculture

July 1956

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Summary In the absence of a clear need for rapid development of the radiation technique of food preservation for our civilian economy at home, and in view of the able way in which development for military purposes is being done under the Quartermaster Corps project, no large research program on radiation preservation of foodstuffs by the USDA seems required at present.

The feasibility of short time, high temperature aging of meat, with microbial spoilage controlled by gamma ray treatment, is to be determined through USDA-sponsored contract research.

It is proposed to investigate also, in research within the Branch and by contract, the low level irradiation treatment (pasteurization) of a number of meats to extend their shelf life. Included are prepackaged meats intended for both refrigerator and frozen storage, hams intended for aging, frankfurters, and sliced, packaged table-ready meat products. The combined application of antibiotic treatment and low level irradiation, with subsequent refrigerated storage, would also be tried since organisms such as the pseudomonads, which are highly resistant to antibiotics proposed for meat preservation, are readily controlled by small doses of radiation.

Dairy products are outstandingly susceptible to quality damage by radiation treatment. The likelihood that research will result in long-term radiation-preserved dairy products even as good as those preserved by present means seems very small.

It is proposed, however, to explore the possibility of using high energy radiation to overcome dormancy of bacterial spores in dairy products and other foods. If feasible this would be of major economic significance. While dormant the spores are very stable to heat and other means of destruction, whereas in the

germinated condition they are easily killed. If through a small dose of radiation the spores could be brought quickly into the first stage of germination, microbial sterilization could be accomplished by mild heating. This would insure greatly improved quality, particularly in low acid foods such as milk, meats and seafoods, which now require pressure heating for long-term preservation.

RADIATION PRESERVATION OF FOODS

First some general remarks. When we preserve foods, what do we try to do? Ideally, to stop all processes that normally go on, so that the food looks and tastes and smells and feels the same after we store it as before, and it is just as nutritious and just as wholesome. We try to stop the life processes of growth and decay, and the increase in the numbers of foreign bodies like bacteria and fungi. We try to stop chemical processes, which alter pigment colors, turn fats rancid, change flavors. And we try to stop physical processes, which change texture and flavor. It isn't always practical to stop all these processes, and often we are satisfied just to slow them down a good deal.

There are a number of means for preserving foods -- heating, cooling, smoking, salting, drying, pickling, fermenting, treating with hormones or other chemicals. All are effective enough to be applied widely to some foodstuffs. None, not even extreme cold, is suitable for all. Almost always the preservative treatment makes a change in an obvious property like aroma and taste, chewing quality, or appearance. Maybe when the processes were new people didn't really like some of these changes. But they put up with them so as to avoid the much worse changes they could expect if the preservative treatment were not used. Expecially if they have grown up with the preserved foods, they regard the "preserved quality" as normal and accept it.

There are several things wrong with all present methods of preserving foods. Let's consider the two most widely applicable methods, heating and freezing. Heat-preserved (canned) foods don't spoil in storage but they do deteriorate in quality when kept at room or warehouse temperature. Some kinds of canned goods deteriorate considerably in a few months, whereas others have a shelf life of a couple of years or more. And the better the quality when freshly packed the faster the foods deteriorate, so subtle are the factors that determine good quality. The deterioration is chemical and can be cut down a great deal by ordinary refrigeration.

Some foods, notably meat, are given so long a heat treatment at so high a temperature to be sure to kill all bacteria that most people don't find them especially palatable. They are too unlike the freshly cooked foods with which we perhaps unconsciously compare them. Eggs can't be heat sterilized without completely changing their character. Heat sterilizing milk spoils its flavor for most people, so a lesser heat treatment, which kills most but not all its microorganisms and only partly inactivates its enzymes, is almost always used to preserve it. Although this pasteurizing treatment gives milk with acceptable flavor and wholesomeness, it still has to be refrigerated to keep bacterial growth and enzyme and chemical deterioration under control.

Freezing, good as it is as a means of keeping fresh- or fresh cooked quality in foods, is not perfect. In principle, if the temperature is low enough, all physical, chemical and life processes slow down so much as to come effectively to a stop. This would require temperatures so very far below zero as to be impractical. There is also the fact that water expands when it freezes. In foods which consist largely of water this may be beneficial in disrupting bacterial cells, leading to the death of some bacteria. It may be very troublesome, though,

in plant tissue with thin cell walls -- lettuce, tomatoes and apples are examples. These foods are living organisms themselves and freezing kills them. Ice crystals formed on freezing rupture or separate the plant cells. Enzymes and the substances they decompose, which are kept separate in the unfrozen tissue, now can come into intimate contact and react, slowly at freezer temperatures (0°F.) but quickly when the food thaws. Liquid oozes from the tissue, which becomes flaccid, flavor is "off", fresh quality is lost, Enzymatic spoilage is so serious that many foods, vegetables particularly, can be preserved by freezing only if the trouble-making enzymes are first inactivated. The only practical way of doing this is by heating. Hence the short hot water or steam "blanch" before freezing. Although this heat treatment kills the living cells and noticeably changes the texture and flavor of the food, it is tolerated as a minor evil.

Aside from the technical problems of preparing good quality frozen foods, there is the continuing requirement that the foods be kept at 0° to -10°F. in warehouses, freight cars, trucks, retail stores, and in household freezers. This requirement can be met only in a flourishing industrial economy like ours, with reliable mechanical refrigeration available just about everywhere at a price most people can afford to pay.

It is inevitable that people should be looking for new ways of preserving food. To be adopted any new method has to offer advantages over present processes. Perhaps the new method provides food which is of better quality, or is cheaper, or has simpler transportation and storage requirements.

It has been imagined that radiation, in the form of either gamma rays or high energy electrons, might provide a useful means of preserving some foodstuffs. Tests of this idea have been going on for something over 10 years. The basic observation is that radiation kills and that the amount of radiation or "dose" needed

to destroy all life in a foodstuff is so small that the temperature rises only a few degrees. Thus it is not improper to refer loosely to radiation as a "heatless means of sterilization". Doubtless by association with canning practice, heatless sterilization suggests a means of preserving food for long storage at ordinary temperatures, without cooking it and without doing any heat damage to its quality. In popular writing and speaking this has led, regrettably if understandably, to description of radiation sterilization as a revolutionary new process in food preservation.

It is important to note the word "sterilization". This has the technical meaning that all living microorganisms are killed. Sterilization preserves foodstuffs only insofar as microorganisms cause spoilage. Whereas microorganisms are the most important cause of food spoilage they are by no means the only cause. When speaking of preservation by freezing, we mentioned the need to inactivate spoilage enzymes. In heat sterilization the heat supplied to kill the bacteria is sufficient to destroy the enzymes, too. But in the radiation process the sterilization dose is nowhere near high enough to completely inactivate the enzymes, with the result that blanching has to be used anyway or the food will spoil.

As a general means of sterilizing foods, radiation has another important technical weakness. The microorganisms to be killed are an extremely minor constituent of the foodstuff, weightwise. Since all of them have to be killed, wherever they occur, the entire amount of food must be bathed in the radiation beam and given the same radiation dose as the microorganisms. It follows that most of the energy in the beam is necessarily spent, not in disrupting the body chemistry of the bacteria and fungi, which is what we want the radiation to do, but in disrupting the chemistry of the foodstuff itself. This usually brings about changes in smell, taste, and appearance. Whether the changes are harmful is

beside the point. If the sensory qualities of the irradiated foods are much different from what we are used to, we will probably find the foods unpalatable. Possibly we could learn to like them, but, so long as we can buy fresh or conventionally preserved foods, it is doubtful if many of us would be interested in learning. And it is doubtful if any American food processor would undertake the considerable financial risk of educating us.

The big research job in radiation food processing is to find how to make the foods look good and taste good despite irradiation. If this problem is not solved, it doesn't matter much what the economics are, whether there are toxic byproducts or not, or whether industry and the Atomic Energy Commission can supply us with sufficiently powerful radiation sources to process food in quantity.

Popular accounts recognize the off-taste, off-odor, difficulty (1,2). They almost always imply or state, though, that the difficulty will be overcome and that the radiation preservation process will be perfected. Food scientists are generally less confident (3,4,5), and some of those most intimately associated with research on radiation preservation have been unwilling to predict that the sensory quality problem will ever be really solved.

It is not evident why the taste-odor-color problem - the "acceptability problem" - of radiation preservation should be any more capable of a general solution through research than the corresponding problem in freezing preservation, canning preservation or preservation by other conventional means.

Effective control of radiation damage has been possible in some foods by devices such as cooling to the temperature of dry ice, by exhaustive removal of oxygen, and by mixing protective chemicals with the food before irradiating it (6). Much of the Quartermaster Corps' million dollar a year radiation preservation program is devoted to trying to find out precisely what the radiation damage to sensory quality is. This is done with the confidence that the best way of avoiding

the damage can then be determined. Whether the best way will be good enough cannot be precisely foreseen.

Radiation preservation research started in a small way in the 1940's, largely as private ventures, with some military support. Until 1953 most of the backing came from the Atomic Energy Commission and electrical manufacturing industries, which hoped to find in radiation preservation of foods large uses for gamma rays from radioactive materials or for electrons from multimillion volt electrical machines. In 1953 the Quartermaster Corps started a much larger project, expected to last at least five years and to cost about six million dollars. Its object is to find out whether radiation treatment can provide better quality food more reliably, more cheaply, and with less waste, to meet the requirements of all the Armed Forces all over the world (7). The need for an improved widely adaptable method for preserving foodstuffs seems much greater for military supply overseas than for civilian supply in the United States. Transportation costs, especially for refrigerated transportation, are high. Transportation abroad in wartime on land and ocean is far less reliable than it ever is at home. In military operations an assured electrical supply cannot be taken for granted, as it is at home. And it is much more important to reduce food loss by spoilage in military operations abroad than in our civilian peacetime economy.

The QM project has been admirably planned and carried out. Due attention is being given to tests for nutritional adequacy and for toxic byproducts in irradiated foods, to development of radiation sources, and to costs. A very important part of the program being carried on in the Quartermaster Food and Container Institute's own laboratories is palatability or "acceptability" testing. This testing is done as closely as possible in the same way and with the same rigor that other processed military rations are judged (8).

Where does radiation sterilization stand now? Within the last few months storage stability tests have been begun by the QM--on three foods, green beans, peaches, and sliced bacon. Storage is at 72° and 100° F., and acceptability will be judged at intervals up to 18 months (9). Tests will be extended to other foods which meet the minimum acceptability requirement when judged shortly after the radiation sterilization has been done.

At the present state of the art many of the most important foods cannot be given anything like a sterilizing dose of radiation without making them unacceptable (2,9). As a consequence the radiation analogue of pasteurization is being seriously tried. In radiation pasteurization perhaps a tenth of the sterilization dose is applied. This destroys a large fraction of the microorganisms and thus greatly decreases the rate of microbial spoilage, while maintaining acceptable flavor and appearance. Storage life of some of the pasteurized foods may be usefully extended several fold. If supplemental refrigeration is required, as it is with heat pasteurized milk, much of the radiation treatment's hoped-for advantage is obviously lost. Apparently the living tissue of some whole fruits and vegetables is so harmed by even a pasteurizing dose that spoilage is faster than in untreated samples Radiation pasteurization of meats will be discussed in detail in the next section.

Milk, cream, butter and cheese are particularly susceptible to radiation damage. More will be said about radiation experiments with dairy products later on. Presumably ice cream must always be kept at a low temperature to preserve its physical qualities, regardless of what other means may be used to retard spoilage.

Food preservation by radiation is considered at some length in the McKinney Report, "Peaceful Uses of Atomic Energy" (10). Of the conclusions reached the following seem especially pertinent (11):

"Radiation preservation of food does not appear likely to replace other methods of food preservation to any substantial extent in the foreseeable future. When economically feasible, it would be a supplement to other methods."

"Radiation preservation techniques appear to be new tools of an advanced and mature technological and industrial society, and are not likely to be readily applied to industrially underdeveloped areas of the world."

"We see no need to change the present rate at which development of radiation preservation techniques for foods and other perishables is going forward, except insofar as military needs may require."

In the absence of a clear need for rapid development of the radiation technique of food preserv·tion for our civilian economy at home, and in view of the able way in which development for military purposes is being done under the QM project, no large research program on radiation preservation of foodstuffs by the USDA seems required at present.

IRRADIATION OF MEATS

Nature of the Problem

Meat consists in the main of the striated muscles of cattle, swine, and sheep, together with certain edible organs such as the liver, heart, brain, etc. Although the tissues concerned are dead in the sense that they are no longer capable of cellular reproduction, most of the enzyme systems involved in tissue reproduction during the life of the animal are still active and chemical changes continue to take place for long periods of time. Meat is subject to spoilage during storage by this continuing enzymic activity, but principally by the action of various microorganisms. Most of these organisms are the result of contamination during

slaughtering and subsequent handling but there is some evidence that there are bacteria already present in the tissues at the time of death. All methods of meat preservation are based on techniques designed to inhibit microbial growth or even kill the microorganisms, and to retard the rate of chemical changes resulting from enzyme action. In the case of heat sterilized canned meats the preservation may be regarded as absolute, and many examples are known of meats that have been found to be entirely wholesome, and of quite desirable flavor and quality, after storage periods of many decades. Most of the meats and meat products that we are familiar with in the civilian market, however, have not been preserved in this way. They are usually refrigerated and the extent to which the preservation is successful depends on many factors, such as temperature, types of microorganisms present, protection from or exposure to air, moisture content, chemical and physical composition, and other interrelated factors.

Of all the factors involved in preservation the control of microorganisms is the most important. In early and now classic investigations, Hoagland, McBryde, and Powick (12) showed that sterile samples of meat held for as long as 103 days at 37°C were edible, although no longer appetizing and of rather disagreeable flavor. In the same investigation the authors report sampling a beef hindquarter held for 74 days at approximately 34°F and finding it highly desirable, of good flavor and quite tender. Furthermore the aging of beef at cool temperatures for periods of from 10 days to 4 or 6 weeks has long been a standard industrial practic At subfreezing temperatures meat can be held for quite long periods of time and Jensen (13) reports on samples of beef in a freezer at temperatures ranging from +14 to 0°F for 40 years. From these and many other investigations too numerous to mention here, it is obvious that the changes due to enzyme action, although marked and important to tenderization and development of both desirable and objectionable

flavors, are not in the case of fresh beef, limiting to storage life. In the case of frozen meat oxidation of fat is a very serious factor in limiting storage life, but can be reduced to a considerable extent by environmental control.

In former days curing of meat by the addition of salt and other substances was an important means of preserving meat. This is no longer the case, however, since modern commercially cured meats and meat products are so mildly cured as to be subject to rapid microbial spoilage.

The most widely applied method of controlling microbial spoilage in the meat industry is that of maintaining a temperature low enough to either retard or prevent growth. In general it can be said that the lower the temperature the more effective the preservation will be. Other methods, such as the removal of moisture, the addition of salt and other chemicals, the control of relative humidity and air circulation around the meat, and combinations of all these with temperature control are also used.

It can be fairly stated that the wide application of refrigeration to meat preservation has created a situation, in the United States, where spoilage, although a limiting factor in keeping time, is not an acute problem. So long as temperature and distribution schedules, which are commercially understood for each type of product, are adhered to there is no serious spoilage problem. This is not to say that the keeping quality of many meats and meat products could not be greatly improved, but merely to point out that present techniques are far from inadequate.

The application of ionizing radiation to meat preservation seems attractive from the standpoint of either preparing sterile products that would not require refrigeration at all or the use of irradiation as a pasteurizing treatment that would extend the shelf life of meats by reducing the microbial load.

Meat Sterilization by Radiation

Exposure of meat to a sufficient dose of x-rays or gamma rays will kill all microorganisms present. The product, if adequately packaged to prevent subsequent contamination, will then remain sterile and be subject only to the autolytic changes induced by the enzymes still present in the meat. As has been pointed out above, this action is not rapid at refrigerator temperatures but does proceed and, based on the data of Hoagland, McBryde and Powick (12), meat that was sterilized but not treated to inactivate enzymes could hardly be expected to keep more than three to four months under the best of conditions (storage at 34°F). There is no point in considering storage at freezer temperatures, since freezing is already known to be an adequate method of preservation and there is no reason for multiplying unnecessarily the preservative techniques applied to a single product. Enzymes can be inactivated by applying preliminary heat treatments. Chicken so treated that was subsequently irradiated and stored for four months at room temperature, although not equal to fresh chicken in quality, was quite acceptable (14). Pomerantz (15) and Siu (16) indicate that pork and pork trimmings for sausage may be similarly handled with good results. Bacon, which has been heated as a part of its normal processing method, keeps well following irradiation.

These apparently successful applications of radiation sterilization to meat are marred by the marked capacity of many meats to develop very pronounced and objectionable odors and flavors when irradiated. It is interesting to note that these objectionable organoleptic changes are less pronounced as the amount of fat in the meat increases (17). Thus beef, contrary to the observations on irradiated pork mentioned above, develops quite undesirable flavor changes when sterilized by irradiation.

The above generalization concerning fat content and irradiation flavor is not always true, since sausages of the frankfurter-bologna type which contain a high proportion of fat are very adversely affected by radiation treatments. Furthermore, mixing ground beef with pork fat prior to irradiation failed to produce a desirable product (18).

In addition to the off flavors produced in many meats by irradiation the problem of damage to color is a serious one. Consumers are accustomed to recognize certain color characteristics as typical of particular meats and meat products. Furthermore, the consumer's ability to recognize changes in meat color is a valuable protection against the possible eating of spoiled meat. Meats irradiated in the absence of oxygen seem to retain their normal color reasonably well (19). In the case of meat treated by a preliminary blanching to inactivate enzymes, the brown methemoglobin color produced by the heat treatment is reduced to a bright red color when irradiated in the absence of oxygen (20). Upon exposure to air the red color, which is unnatural in the case of pork and chicken, soon reoxidizes to the brown form.

The feasibility of preparing a sterile meat product by irradiation is limited mainly by the undesirable changes in flavor and odor induced by the treatment. Much research work will be required to solve this difficulty. At present little is known about the chemical changes induced by radiation which underlie these changes. Hannan (19) reviews the attempts that have been made to control these undesirable changes. The most successful seem to be the application of freezing at low temperature (approx. -30°F) prior to irradiation. However, since freezing of properly protected meats at such temperatures is a very excellent method of preservation, there seems little validity in expending energy to reduce product temperatures to such an extent and then applying an entirely different and admittedly

less effective preservative treatment, unless low temperature storage is not available or too expensive. It may well be that future studies will advance our knowledge to the point where chemically protective substances can be used to prevent the development of radiation flavors. In the meantime this difficulty (control of off-flavors) stands as an absolute limit to the successful application of irradiation of all but a few meats.

Those who are ardent advocates of the application of radiation to meats generally speak in terms of a sterile product capable of withstanding long storage at ordinary temperatures. There is some reason to question the need for such a product in view of the generally successful method of meat handling and distribution now used in the United States. There is, however, a need for such products by special consumers such as the Quartermaster Corps, campers, and others and a limited market might be expected. Furthermore, if such products were equal in quality to meats preserved by heat or low temperature, a considerable demand based on their convenience to consumers could be expected. The thought is also pertinent that if a research effort equal in intensity to that now expended on radiation were applied to the improvement of heat sterilized meats, products very superior to those now available might result.

Meat Treated by Substerilizing Doses of Radiation

The radiation doses necessary to completely sterilize meat are necessarily high (over 2.5×10^6 rep*) and many of the deleterious effects could be expected to be greatly reduced, or even absent, at lower levels of irradiation. Most of the microorganisms found on meat are non-spore-forming bacteria, yeasts and molds which would be readily inactivated by much lower radiation doses. There are many

* The rep is the usual unit of radiation dose and expresses the amount of energy dissipated in a gram of a material irradiated. One million rep amounts to about two calories, which, if supplied instantaneously, would raise the temperature of meat or other food consisting mostly of water about 2°C.

practical situations in which microbial populations could be controlled in this way. An analogous situation familiar to all is the pasteurization by sub-lethal heat treatment which kills many microorganisms but does not affect spores or more resistant vegetative cells. Because of the close analogy to sub-lethal heat treatment, such low level irradiation is also referred to as pasteurization.

In the field of meat tenderization by high temperature aging there is an obvious need for a treatment having great penetrative power that could be used to control microbial growth and could be applied by an automatic procedure. Gamma rays could very well be the answer to this need. The Eastern Utilization Research Branch of USDA is sponsoring through contract an investigation of radiation pasteurization in meat aging (21). There is reason to suppose that gamma ray doses of less than 100,000 rep may be effective in this application. There are also many instances of desirable prepackaged meat products that have an unusually brief shelf life and are therefore difficult to market. It may well be that low doses of radiation applied to such products after packaging would extend their shelf life for a long enough time to assure reasonable marketing distribution. If very cheap and easily applied radiation sources could be designed and built, a prefreezing treatment would be helpful in preventing post thawing microbial damage to frozen meat.

Gomberg et al. (22) have described an installation capable of irradiating hog carcasses on a continuous basis in a plant having a capacity of 2,000 hogs per day for the purpose of inactivating Trichinella spiralis (the causative agent of trichinosis). The proposed installation would deliver irradiation to the surface of the meat at a level of 30,000 rep or 25,000 at the center of the carcass. The authors estimate that this treatment would cost .2 cent per pound of pork and would adequately inhibit the development of larval parasites and the reproduction of adults. In view of the now adequate garbage cooking laws and other control

procedures there may be some question as to the economic feasibility of this proposal. While its institution would bring about some saving of effort on the part of the Department's Meat Inspection Branch, it is doubtful if any considerable financial saving to the taxpayer could result. There would undoubtedly be a saving to the packer if certain procedures now necessary for trichinae control could be dispensed with, but an estimation of their extent is not feasible for this review. It might be pointed out, however, that only about 10 percent of the pork carcass is used in products requiring trichinae control.

Summary and Recommendations

The complete sterilization of meats and meat products by irradiation is quite possible but generally results in serious losses of product quality. Although there does not seem to be great likelihood of wide application of complete radiation sterilization to meats, future research might well be directed toward investigating the chemical and physical changes produced in meat as a result of treatment by ionizing rays. The Department should be well informed of any developments in this area and, for this purpose alone, it would be reasonable for the Eastern Utilization Research Branch to take some part in the research.

The most promising application of irradiation in the meat field seems to lie in the use of low level doses for pasteurizing treatments. The Branch is already entering this area of work through a contract. Work in this area could well be expanded both by contract and by active research within the Branch. Problems which might be investigated include the pasteurization of prepackaged meats intended for both fresh and frozen storage, the irradiation treatment of hams intended for aging, and the pasteurization of frankfurters and of sliced, packaged, table-ready meat products to extend shelf life. The combined application of antibiotic treatment and low level irradiation with subsequent refrigeration is also of interest since organisms such as the pseudomonads which are highly resistant to antibiotics proposed for meat preservation are readily controlled by low level irradiation.

Aside from its primary utility as a preservative treatment, radiation sterilization can be used to furnish meat samples free of bacteria and unchanged by heat which could be used in many experiments dealing with the effects of bacteria and enzymes on meat. When Departmental facilities for irradiation are available, the use of such experimental material will be greatly facilitated.

PRESERVATION OF DAIRY PRODUCTS BY HIGH ENERGY RADIATION

The Need for Improved Methods

The application of mild heat as presently employed, when used in conjunction with refrigeration provides an effective, practical and satisfactory method for ensuring short-term preservation of fluid milk and some of its products. Long-term preservation of fluid and concentrated milk and cream is currently achieved by pressure heating, in hermetically sealed cans, which then may be stored with or without refrigeration; the method is safe and practicable, and provides an acceptable product, although not without appreciable color change and a somewhat cooked flavor and odor. Since pressure heating, with its limitations, is the only known practical method for ensuring long-term preservation of milk and cream, there is a real need for a method which will achieve this objective with retention of fresh-product quality. Research to this end is being actively pursued not only in Federal but also in State agencies, using modern techniques and highly trained personnel.

Heat sterilization of vacuum-packed cheese spreads has not proved commercially feasible for reasons of quality impairment. A method of processing these products which would dependably destroy all health- and spoilage-significant microorganisms, without significant alteration in their organoleptic properties, would be a contribution to the dairy industry. Healthwise, the key organism to be controlled is the ever-dangerous Clostridium botulinum, spores of which have been demonstrated in cheese spreads, but which in this substrate do not normally germinate and produce toxin.

Butter is subject to two chemical changes in storage which seriously impair its quality: 1. the development of a rancid taste and odor; 2. oxidative deterioration. The former, caused by the activity of the enzyme lipase, which hydrolyzes the butterfat--can be easily avoided by heating the cream at 165°F for 30 minutes before churning, which inactivates the lipolytic enzyme. Oxidative deterioration is much more difficult to combat and can be entirely prevented only by the complete deaeration of the butter, which is difficult and contributes to the cost. The use of good cream, thorough washing of the butter and low-temperature storage are other factors essential to the manufacture and successful storage of high quality butter.

In the manufacture of milk powder a preheating of the milk is essential, to ensure satisfactory storage life; this heating although imparting a somewhat cooked flavor and odor, inactivates the enzymes and produces reducing substances which retard the development of oxidized flavors. The marketing of skim milk powder presents no serious problems. It is put out in two forms, one preheated at a relatively high temperature (185°F--30 min.), valued by commercial bakers because of the larger loaf volume--and for whom the cooked flavor is not detrimental; another form of skim milk powder is prepared from milk heated at 145°F for 30 min. and is used for household purposes; the use of this product would be extended if preliminary heating of the milk could be avoided. Whole milk powder is much more subject to oxidative deterioration than skim. This can be prevented by thorough deoxygenation, but is difficult to accomplish, especially the removal of the occluded oxygen, and the treatment adds to the expense. The use of antioxidants will minimize but not prevent storage deterioration and may preclude the necessity of preheating. However, the use of these compounds is not, at present, permitted by the Food and Drug Administration.

It is well known that gas- and objectionable flavor-forming bacteria are usually present in raw milk and that, under favorable conditions for growth, they will form defects in cheese. However, practical and economical means are available for usually preventing the development of such defects during the making and ripening of cheese. Gas and flavor defects seldom develop in cheese made from milk that is of good quality and has been pasteurized, provided an active lactic acid-forming starter is used and proper manufacturing methods are employed. Most of the defect-forming species of bacteria are killed during pasteurization and thos that may survive pasteurization are usually inhibited by the acid formed by the bacterial starters during the making of cheese. Thus, the defect-forming bacteria can be controlled and favorable conditions provided for the growth and biochemical activities of the added starter bacteria during the making and ripening of cheese. Continued microbial growth and activity during cheese ripening is essential to the development of the desired characteristic flavor and texture of cheese.

Technical Findings to Date

The ionizing radiation dose required to sterilize fluid milk has been variousl reported to be 1.4×10^5 to 1.6×10^6 (23), 10^6 (24), 7.5×10^5 (25), and 1.7×10^6 rep (26,27). Gaden et al. (28) reported that at 73,000 rep, there was imparted to the milk the flat flavor characteristic of pasteurized milk; above 100,000 rep, the milk began to acquire an undefined off-flavor, although doses up to 1.83×10^6 rep resulted in no apparent physical changes. Storage life of the irradiated milk was greatly prolonged. Some protection against radiation side-effects is afforded by the use of antioxidants (19,29). O'Meara (30) noted an undesirable flavor in milk irradiated with 100,000 rep at 50-60°F; the effect was decreased slightly on storag and was reduced by irradiation in the frozen state (29,30). Skim milk irradiated in No. 2 cans above 2×10^6 rep, acquired a malty caramel-like flavor, and after

5×10^6 rep developed a brown color (31). Radiation-induced off-flavor in a milk beverage was reportedly eliminated by stripping with inert gas (6); the same authors also claimed that flash heating of raw milk to 78°C for 30 seconds, followed by irradiation with 500,000 rep within 10 minutes, produced a sterile product.

Irradiation of concentrated milk, dried milk and butter has met with little success. The latter becomes bleached, develops a tallowy, or rancid, flavor and odor, which increases progressively with the dose (19,32). Hannan (19) found that irradiation of butterfat in the completely solid state (-70°C) or in the liquid state (37°C), caused much less flavor and odor than at room temperature; only by the almost complete removal of oxygen were the flavor and odor changes markedly diminished. Ionizing radiation sufficient to sterilize powdered milk imparts to the reconstituted product serious off-flavors which cannot be satisfactorily eliminated even when diluted with 80 percent powdered milk or 80-90 percent fresh milk (8). Oxidized flavors were noted by Hannan in dried milk, irradiated at 2×10^6 rep (19). Robinson (33) observed that irradiation of powdered milk made it more sensitive to oxidative rancidity and thus reduced its storage life.

Irradiation of cheese induces an oxidized flavor arising from the fat which makes it more sensitive to rancidity--indications are that complete exclusion of oxygen may be necessary for long storage (19). Brownell et al. (34, 35) found that cottage cheese, irradiated in air in polythene bags, developed a strong "smoky" and "goaty" flavor with doses of 2×10^6 rep; mold growth was prevented by 85×10^5 rep, but after 7-10 days of storage the cheese acquired a sharp odor. Cottage cheese made by Dunn et al. (24) from radiation-sterilized milk (2×10^6 rep) with the use of a starter organism, did not differ organoleptically from similar cheese made from unirradiated milk. Radiation studies on cheese spreads have been reported (36); seven series of soft surface, ripened cheese samples were inoculated

separately with type A and type B Cl. botulinum spores and irradiated at different dose levels. Analyses for Cl. botulinum toxin up to 90 days of storage revealed that 3 megarep completely inhibited growth and toxin formation. Samples receiving 3, 2, and 1.5 megarep had a non-appetizing malty odor and a pungent oxidized flavor; at lower doses organoleptic properties were similar although less intense. At the higher radiation levels, a bleaching of the color and some breakdown of physical structure occurred; a later report (37) indicated that type A spores required for their inactivation 8.0×10^5 to 1.1×10^6 rep, type B, 5.5×10^5 rep. Huber (38) stated that irradiated flavor in cream cheese disappeared after 66 days of storage at room temperature in the original metal foil wrapper.

In tests with raw and pasteurized whole milk, evaporated milk, cream, butter, and Cheddar cheese and cream cheese, Kung et al. (39) found that gamma radiation at 80,000 rep per hour caused severe losses in nutritive quality before sterilization was accomplished. When raw whole milk was irradiated with 480,000 rep, the percent destruction of vitamins was as follows: vitamin A 70, carotenoids 40, riboflavin 37, tocopherols 61, reduced ascorbic acid 100; for other milk products, the vitamin losses were somewhat less, but remained high. Essentially similar results were reported by Gaden (23) and Gaden et al. (28), who also observed that irradiation with 146,000 rep had little effect upon vitamin A and riboflavin.

Studies on the effect of ionizing radiations upon enzyme systems have established that most, if not all, biological catalysts are relatively radiation-resistant as they exist in their natural state (40,41,42). Proctor observed that 5×10^6 rep did not completely inactivate peroxidase in milk and estimated that the radiation-inactivation dose for enzymes is 10 to 20 times that required to kill microorganisms (32). Irradiation with 960,000 rep only slightly reduced the activity of milk phosphatase, and the catalase of Staph. aureus lost only 1/3 of its

activity on irradiation with 700,000 rep (43).

Prospects

On the basis of existing knowledge and experience there seems little prospect that ionizing radiations will, within the foreseeable future, supplant heat and refrigeration as a means of preserving milk and other dairy products. The considerations which lead to this conclusion are:

1. Milk and other fat-containing dairy products when irradiated at dose levels far below that required to achieve microbial sterilization, undergo organoleptic changes which render the products unacceptable to critical consumers (19,28,30,32). Although deep or surface irradiation of dairy products at dose levels below that inducing organoleptic changes may greatly reduce the microbial flora, and thus retard spoilage (28), there is, at present, no reason to believe that this could be accomplished more advantageously by irradiation than by the conventionally used methods.

2. Natural and microbial enzymes in milk and milk products cannot be inactivated by irradiation without rendering the products virtually inedible (39,41,42); hence a supplemental heat treatment would be necessary, entailing additional cost and inconvenience.

3. Irradiation of dairy products at dose levels far below those needed to kill all microorganisms results in substantial losses of important milk vitamins (27, 39, 42), which, in general, are depleted to a much less extent by conventionally used heat processing methods (43).

4. Although the economics of food irradiation is difficult to assess at present, it is a reasonable inference, based on known facts, that the preservation of dairy foods even in the limited areas where it might be considered, would cost no less, and possibly more, than presently used methods (44).

5. Feeding tests with irradiated dry milk and butter, although revealing no true or definite toxicity, slightly but consistently decreased the growth rates and reproduction as compared with the controls (45).

It is concluded that the prospect for commercial application of radiation treatment of dairy products is not at this time sufficiently bright to warrant more than one USDA-sponsored effort to further explore possible applications of radiation in the dairy field. However, a continuing watch is being kept on results of radiation research. Should later developments indicate that radiation-preserved dairy products with superior organoleptic quality are in fact attainable, USDA will support wholeheartedly the research and development needed to make the process practical.

Proposal for USDA Sponsored Research

It is suggested that a project be set up to explore the possibility of utilizing high energy radiation as a means of overcoming delayed germination (dormancy) of bacterial spores. The phenomenon of delayed germination, which is exhibited by only a small fraction of the spore population, is of major economic significance, since in the resting, ungerminated condition, spores are very stable to heat and other destructive influences, whereas in the germinated or partly germinated condition they are very labile; hence if all spores in food products could be brought into the beginning stage of germination within a short period of time, microbial sterilization could be accomplished by relatively mild heating, insuring greatly improved quality, particularly in low acid foods such as milk, meats, seafoods, etc. where pressure heating is essential to long-term preservation. The proposed study contemplates the preparation of a series of milk samples containing dormancy-tending spores of Bacillus subtilis, and the subsequent exposure of part of these samples to graded, sublethal gamma or cathode radiation. Germination of irradiated and

control spores would then be studied for evidence of radiation-induced stimulation. It is suggested that this project be conducted in the Dairy Products Section, Eastern Utilization Research Branch, in collaboration with suitable personnel at a radiation facility center.

REFERENCES

1. Kaempffert, W., "Science in Review," The New York Times, January 22, 1956.

2. "Radiation Sterilization of Foods," Hearing before the Subcommittee on Research and Development of the Joint Committee on Atomic Energy, May 9, 1955.

3. Tischer, R. G., Sixth Research Conference, American Meat Institute, Chicago, March 25, 1955.

4. Ball, C. O., Food Tech., 9, 588 (1955).

5. Proctor, B. E., "Radiation of Foods: A Canvass of Facts and Opinions," page 17, The Refrigeration Research Foundation, Colorado Springs, 1955.

6. Huber, W., Brasch, A., and Waly, A., Food Tech., 7, 109 (1953).

7. "Radiation Sterilization of Foods," A symposium sponsored by the Quartermaster Food and Container Institute, Chicago, June 8, 1955.

8. Quartermaster Corps Project No. 7-84-01-002, Internal Contract - "Survey of the Effect of Irradiation on Selected Foods," Report for period March 1 to October 15, 1955.

9. Quartermaster Corps Project No. 7-84-01-002, Internal Contract - "Stability Studies on Irradiated Foods," Report for period August 15 to November 1, 1955.

10. "Report of the Panel on the Impact of the Peaceful Uses of Atomic Energy to the Joint Committee on Atomic Energy," Volume II, pages 177-214, Washington, 1956.

11. ibid., Volume I, pages 73-4.

12. Hoagland, R., McBryde, C. N., and Powick, W. C. Changes in Fresh Beef During Cold Storage above Freezing. USDA Bull. 433 (1917).

13. Jensen, L. B., "Meat and Meat Foods." New York: Ronald Press, 1949.

14. Sulzbacher, W. L., Private communication.

15. Pomerantz, R. C., Quartermaster Food and Container Institute, Private communication.

16. Siu, R. G. H., In "Radiation Sterilization of Foods," Hearing before the Subcommittee on Research and Development of the Joint Committee on Atomic Energy, 84th Congress, 1955, p. 47.

17. Doty, D. M., American Meat Institute Foundation, Private communication.

18. QMFCI Annual Status Report (1 Nov. 1954 - 31 Oct. 1955) Radiation Preservation Project.

19. Hannan, R. S., "Scientific and Technological Problems Involved in Using Ionizing Radiations for the Preservation of Food." Food Investigation Special Report 61, London, 1955.

20. Turner, E. W., Quartermaster Food and Container Institute, Private communication.

21. American Meat Institute Foundation, Chicago. "Studies on High Temperature Aging to Increase Tenderness of Lower Grades of Beef." USDA contract 12-14-100-486(73) dated June 18, 1956.

22. Gomberg, H. J., Gould, S. E., Nehemias, J. V., and Brownell, L. E., Design Fission Irradiator to Break Trichinosis Cycle. Food Eng. 26, (No. 9) 78 (1954).

23. Gaden, E. L. Food Irradiation and Associated Studies. Quarterly Progress Report, December 1, 1951. (AEC publication NYO - 3317).

24. Dunn, G. G., Campbell, W. L., Fram, H., and Hutchins, A. 1948. Biological and Photochemical Effects of High Energy Electrostatically Produced Roentgen Rays and Cathode Rays. J. Applied Phys. 19, 605-616.

25. Proctor, B. E., and Goldblith, S. A. 1951. Electromagnetic Radiation Fundamentals and their Application in Food Technology. Advances in Food Research 3, 119-56.

26. Brownell, L. E., Lawrence, C. A., and Graikoski, J. T. 1953. Sterilizing Food by Cold Gamma Rays. Refrig. Eng. 61, 55.

27. Lawrence, C. A., Brownell, L. E., and Graikoski, J. T. 1953. Effect of Cobalt-60 Gamma Radiation on Microorganisms. Nucleonics, 11 (1), 9.

28. Gaden, E. L., Henley, E. J., and Collins, V. P. 1951. Preservation of Milk by Radiation. Food Tech. 5, 506-9.

29. Proctor, B. E., Goldblith, S. A., Bates, C. J., and Hammerle, O. A. 1952. Biochemical Prevention of Flavor and Chemical Changes in Foods and Tissues Sterilized by Ionizing Radiations. Food Tech., 6, 237-42.

30. O'Meara, J. P. 1949. The Effect of Supervoltage Cathode Rays on Fluid Foods. B.S., M.S. Thesis, Dept. Food Technol., Mass. Inst. Technol.

31. Josephson, D. V., Day, E. A., and Patton, S. 1955. Odor and Flavor Problems in Radiation Sterilization of Foods. QM Progress Report, Sept. 3 - Nov. 2, Contract DA19-129-qm-375.

32. Proctor, B. E. 1952. Cathode Rays and the Dairy Industry. Certified Milk. May, p. 15.

33. Robinson, R. F. 1954. Some Fundamentals of Radiation Sterilization. Food Tech., 8, 191-194.

34. Brownell, L. E., et al. 1952. Utilization of the Gross Fission Products. Engng. Res. Inst. Univ. Mich., Progress Report No. 2. (COO-90).

35. Brownell, L. E., et al. 1952. Utilization of the Gross Fission Products. Engng. Res. Inst. Univ. Mich., Progress Report No. 3. June (COO-91).

36. Wagenaar, R. O. 1952. Radiation Studies on Cheese Spreads. Food Res. Inst. Progress Report No. 1, June 18, 1951 - March 31, 1952.

37. Wagenaar, R. O. 1953-1954. Radiation Studies on Cheese Spreads. Food Res. Inst. Progress Report No. 3, July 1, 1953 - March 31, 1954.

38. Huber, W. 1948. Electronic Preservation of Food. Electronics. 21 (3), 74-9.

39. Kung, H. C., Gaden, E. L., and King, C. G. 1953. Vitamins and Enzymes in Milk. Effect of Gamma Radiation on Activity. J. Agric. and Food Chem., 1 (2), 142-4.

40. Proctor, B. E., and Goldblith, S. A. 1952. A Critical Evaluation of the Literature Pertaining to the Application of Ionizing Radiations to the Food and Pharmaceutical Fields. AEC Contract No. AT (30-1)-1164, Jan. 1 (NYO 3337).

41. QM Quarterly Status Report (1 August - 31 October) 1955. Radiation Sterilization Project 7-84-01-002. p. 34.

42. Proctor, B. E., Coleman, M. T., and Goldblith, S. A. 1952. Effect of High Energy Cathode Rays on the Catalase Activity of Micrococcus pyogenes var. aureus. J. Bact. 63, 337-9.

43. Hunziker, O. 1949. Condensed Milk and Milk Powder. 7th Ed., p. 525. LaGrange Illinois: The Author.

44. Clifcorn, L. E. 1955. The Food Industry's Attitude toward Radiation Sterilization. Nucleonics, 13, No. 1, p. 39.

45. Brownell, L. E., Becker, L. and Youmans, J. B. 1955. The Radiation of Foods, Digest of Conference at Stockyards Inn, Chicago, Illinois, Jan. 19,20, p. 12.